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1257 E82-10314

CR-168889

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(E82-10314) IMPROVED DEFINITION OF CRUSTAL
MAGNETIC ANOMALIES FOR MAGSAT DATA Final
Report (Phoenix Corp.) 23 p HC A02/MF A01

N82-24587

CSCI 08G

Unclass

G3/43 00314

IMPROVED DEFINITION
OF CRUSTAL MAGNETIC ANOMALIES
FOR MAGSAT DATA

-FINAL REPORT-

on

Contract No. NAS5-25882

for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

by

Phoenix Corporation
1700 Old Meadow Road
McLean, Virginia 22102

15 March 1982

RECEIVED

MAR 24, 1982

SIS/902.6

M-015

FINAL

BIBLIOGRAPHIC DATA SHEET

1. Report No.	2. Govt. Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle IMPROVED DEFINITION FO CRUSTAL ANOMALIES FOR MAGSAT DATA - Final Report		5. Report Date February 1982	
7. Author(s) R.D. Brown, J.F. Frawley, W.M. Davis, R.D. Ray, E. Didwall, and R.D. Regan		6. Performing Organ.Code	
9. Performing Organization Name and Address Phoenix Corporation 1700 Old Meadow Road McLean, Virginia 22102		8. Performing Organ.Rpt.No.	
12. Sponsoring Agency Name and Address NASA/Goddard Space Flight Center Geophysics Branch (R.A. Langel) Greenbelt, Maryland 20771		10. Work Unit No.	
		11. Contract or Grant No. NAS5-25882	
		13. Type of Rpt. & Per. Cov. Technical Report (Type III) Final Report	
14. Sponsoring Agency Code			
15. Supplementary Notes ORIGINAL PAGE IS OF POOR QUALITY			
16. Abstract MAGSAT vector magnetometer data can be routinely corrected for external field effects such as DS, DST, and Sq, by filtering the data for long wavelength harmonics. Separation of the low altitude external fields from those at high altitude is effected by means of dual harmonic expansions in the solution of Dirichlet's problem. The filter has been developed to act on arc lengths of one orbit period, and initial tests on MAGSAT data from orbit 1176 show reduction in external field residuals by ± 10.95 nT RMS in the radial component.			
17. Key Words (Selected by Author(s)) MAGSAT External Fields Filter Regression Ring Current, Daily Variation, Harmonic		18. Distribution Statement	
19. Security Classif. (of this report) N/A	20. Security Classif. (of this page) N/A	21. No. of Pages 25	22. Price

IMPROVED DEFINITION OF CRUSTAL ANOMALIES FOR MAGSAT DATA

ABSTRACT

MAGSAT vector magnetometer data can be routinely corrected for external field effects such as the ring current and the daily variation, by filtering long-wavelength harmonics from the data. Separation of fields due to low-altitude sources from those of high-altitude sources is effected by means of dual harmonic expansions in the solution of Dirichlet's problem. This regression/harmonic filter procedure is applied in an orbit-by-orbit basis, and initial tests on MAGSAT data from orbit 1176 show reduction in external field residuals by 24.33 nT RMS in the horizontal component, and 10.95 nT RMS in the radial component.

INTRODUCTION

The effectiveness of the MAGSAT mission for delineation of crustal magnetic anomalies is hampered by the presence of external field contamination in the data. Fields from the ring current and the daily variation are as large as that of all but the largest crustal magnetic anomalies at satellite altitude. (Sugiura and Hagan, 1979). The patterns of the ring current and the daily variation are hemispherical or global in scale, but because they can change suddenly in time, the associated external fields measured at the satellite can alias with those of the generally shorter wavelength crustal anomalies. While the gross features of the ring current and the daily variation are fairly well known, they are not amenable to predictive physical modeling because of their unpredictable variability in response to the solar wind. Sugiura and Hagan [1979] have found that the Solar quiet (Sq) daily variation is well represented by spherical harmonics of degree 4, for example, but these model coefficients vary from hour to hour. Far from being a predictive model, this representation is purely descriptive, being based on magnetograms from many magnetic observatories distributed around the globe. An example of the effects of these ionospheric currents on satellite data is illustrated in Figure 1, showing several POGO satellite passes in which the field due to the daily variation is apparent and is verifiable by comparison with observatory data. Although this data is far removed in local time from the noon-time peak in daily-variation amplitude, its effect is still significant compared to that of the crustal magnetic anomalies of interest. Plots of the field due to the Sq current system on December 27, 1964, 1700 hrs GMT are shown in Figure 2 for various latitudes and altitudes. Note that this time corresponds to a period of minimum solar activity, while the MAGSAT mission was flown during a solar maximum. Figure 3 illustrates the increase in Sq effects to be expected in a period of high solar activity.

The ring current is somewhat easier to model, since the geometry is simpler and the Dst index describes its strength. Figure 4 shows field residuals for several passes over the same area for different solar wind conditions, as evidenced by the variability of the Dst index. The solid lines in each plot are the correction devised by Cain and

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Davis [1973] for this effect. This correction is based on a least squares curve fitting to the observed data, a procedure which requires careful attention to the epoch and length of the data arc to minimize aliasing with the crustal signals of interest. A physical model of the ring current, with current density varying as a function of the Dst indices, is attractive because of its simplicity. Such a model remains basically descriptive in nature, however, being dependent on the analysis of observatory magnetograms for the Dst indices, which may change hourly.

Other procedures for removing external field effects from the satellite magnetometer data are based on minimizing the variability between individual data profiles over the same area at different times. Reagan, et al. [1975], used a semi-quantitative visual intercomparison technique for editing severely contaminated passes. Mayhew [1979], has employed the fitting of linear or quadratic functions of varying lengths to minimize the interpass variability.

The problem with the above techniques is that they are all somewhat ad hoc in nature, and are not easily generalized into an algorithm for routine processing of satellite magnetometer data. In general, the data must be carefully selected by geographic area, arc length, and time, and a year or more may elapse before enough observatory data can be collected and analyzed to produce models of Sq or Dst indices. Even at best, the resulting models of the daily variation and the ring current are global averages, and cannot describe the sudden variations in time and space which can occur in these current systems. Furthermore, these models have been developed to deal only with scalar total field data, not the more variable vector field components provided by the MAGSAT mission.

This report describes the results of an investigation to develop a method for routine removal of the most persistent external field effects from the MAGSAT data. The proposed approach involved modifying existing ring current correction procedures to use indices such as DS and Dst, and simplifying the Sugiura and Hagan model for Sq currents. Lack of timely data from magnetic observatories, and early success with regression models for correcting the ring current, led us to adopt a different approach. A prototype method which uses knowledge of the spectral content of the external fields, but which is insensitive to geographic area and can be used routinely in near-to-the-measurement-time, was developed. The following sections describe this prototype method and the results of its application to MAGSAT vector magnetometer data.

EXTERNAL FIELD MODEL EVALUATION

In the early phases of this investigation, an evaluation was made to assess the application of existing models for the daily-variation and the ring current. These efforts concentrated on the addition of Dst indices to Cain's ring current model, and on simplifying the Sugiura and Hagan [1967] model for the daily variation to a procedure more amenable to prompt, routine processing.

Ring Current

To fully appreciate the meaning of the Dst index, it is important to understand its derivation. The ring current is thought of as a more or less symmetric ring of current at about 5 earth radii, located in the geomagnetic equatorial plane. This current is generated by the drift of protons and electrons trapped below 7.9 earth radii between the dipolar main field and the magnetopause. The drift is a function of the radial gradient in magnetic field intensity, and results in a net westward current vector. During magnetic storms, the increased injection of particles into the magnetosphere, and the increased solar wind pressure cause the ring current to intensify and become less symmetric, depressing the magnetic field strength observed at the earth's surface by as much as 100 nT. Sugiura [1964] developed the Dst index as an indicator of the strength of the ring current. He models the field due to the ring current as a Fourier series in the geomagnetic equatorial plane as:

$$D = A_1 (T) \sin [(T + \lambda) + \alpha_1(T)] + A_0(T) \quad (1)$$

where T is universal time, λ is local time, A_0 , A_1 , and α are model coefficients, corresponding to amplitudes and phase angles, respectively.

By observing the horizontal field component at 4 terrestrial observatories, and adjusting the observations for the latitude of the station, one may solve for these amplitudes and phases. The Dst index is A_0 , the symmetrical field strength due to the undisturbed ring current at the geomagnetic equator. The amplitude A_1 is the DS index, representing the asymmetric component of the ring current during disturbances. Except for these asymmetries in the ring current field, it is approximately uniform and parallel to the earth's dipole axis in the vicinity of the earth. Thus it aliases with other fields of similar characteristics, such as those of the magnetotail and magnetopause currents.

A preliminary evaluation was performed of the Cain and Davis [1973] ring current correction in comparison with the use of best fitting 2nd degree polynomials, best-fitting 3rd degree cosine series, and a model using the first three terms of the spherical harmonic expansion for a uniform field with coefficients proportional to the Dst and DS indices. Seven colinear POGO data passes were selected having continuous coverage from 50 degrees South to 50 degrees North over each of two test areas. These data were corrected using each of the four techniques described above. All of the techniques gave very similar appearing results, with no significant differences in RMS of residuals or commonality of passes. The total field due to the ring current correction was roughly proportional to $\cos^2\phi$, where ϕ is geomagnetic latitude.

Solar Quiet Daily Variation

In developing a model for Sq, Sugiura and Hagan [1967] used a spherical harmonic formulation for the associated scalar potential which accounted for the direct Sq field and its secondary induced field in the earth for a terrestrial observatory. The scalar potential is written as:

$$W(T, r, \beta, \lambda) = a \sum_{n=1}^{\infty} \sum_{m=0}^n \left\{ \left[g_n^{(e)}(T) \cos m\lambda + h_n^{(e)}(T) \sin m\lambda \right] \left(\frac{r}{a} \right)^n + \left[g_n^{(i)}(T) \cos m\lambda + h_n^{(i)}(T) \sin m\lambda \right] \left(\frac{a}{r} \right)^{n+1} \right\} P_n^m(\cos \beta) \quad (2)$$

where r is radial distance of the station from the geocenter, β is geographic colatitude, λ the geographic longitude, a is the mean radius of the earth, $P_n^m(\cos \beta)$ is the associated Legendre function of degree n and order m , and g_n^m , h_n^m , superscripted by e or i for external and internal, are the coefficients to be determined as functions of the universal time T .

The scalar magnetic field intensity, derived from this expression by application of the gradient operator, is measured hourly at about 60 ground stations distributed around the world, for a period of days. These observations are used in a least squares solution for the coefficients g_n^m and h_n^m up to degree and order 4. A new solution is made for each hours data. While the 4th order model coefficients are found to be adequate to represent the Sq daily variation for a given hour, Sugiura and Hagan [1979] find considerable transient variability in the current pattern from hour to hour. Indeed, Davidson and Heirtzler [1968] suggest that the rapid variation background in terrestrial observations of the magnetic field is due to turbulence in the Sq current system.

In our evaluation of this model, we initially concentrated on simplifying the 4B term spherical harmonic model to one with fewer terms and with coefficients proportional to readily available indices of the state of the solar wind, such as Dst, Kp, or Ap. Results for POGO satellite data were inconclusive, due to the presence of orbit errors. Our efforts then turned to collecting, processing, and analyzing magnetograms from magnetic observatories for the MAGSAT mission time period in order to construct a reference model for the Sq currents.

Evaluation Summary

The spatial variation of the ring current is sufficiently simple that a regression analysis on the actual satellite data using a low order harmonic model is found to perform as well as more sophisticated models using prescribed DS and Dst indices. Since these indices must be developed from analysis of magnetic observatory records, and since they represent global averages of the ring current over hour-long time intervals, the regression analysis approach is more suitable for

routine correction of satellite magnetometer data.

These same arguments apply to the routine correction of the daily variation. After nearly two years of collecting and processing magnetic observatory magnetograms, we still have insufficient data to model the ionospheric Sq currents for the MAGSAT time frame. Efforts to reduce the number of terms in the presently available Sugiura and Hagan model, and to develop coefficients which were proportional to magnetic indices yielded results which were inconclusive in testing with POGO data. This approach still does not provide for corrections in case of sudden changes in time or space of the Sq current distribution.

Our search for a simplified method which can be used in a routine manner turned to using the Sugiura and Hagan mathematical formulation in a regression mode. We already know the harmonic content of the daily variation field well enough to accurately model its spectral behavior in satellite data. Such an approach would require only the existence of the satellite data and be better able to cope with sudden changes in the Sq current distribution.

APPROACH

It is apparent from the foregoing review that both the ring current and the daily variation can be represented by a rather low order, long wavelength, model, albeit one which might change rapidly in space and time. But rather than create a separate correction model for each phenomena, we can consider a single harmonic model to correct for all long wavelength external fields manifest in an orbital arc of MAGSAT data by regression analysis on the data. The mathematical statement of this approach involves recasting equation 2 in the form of Dirichlet's problem at the satellite orbital altitude.

If we know the value of a harmonic function on a boundary surface, then we may compute the value of the function everywhere it remains analytic. In the case of equation 2, the boundary surface is the surface of the earth. The external functions, being analytic above the earth, describe the incident external field and its reflection from the earth's surface. The internal functions, analytic inside the earth, describe the fields from the currents induced by the daily variation. In our application, the boundary is the MAGSAT orbit, which we assume is a closed curve in inertial space, and the external functions and internal functions merely describe the long wavelength behavior of the scalar magnetic potential above and below the orbit altitude, respectively. Thus these functions, which we shall term inner and outer functions to avoid confusion with the conventional definition of the internal and external field, represent the fields from all sources, regardless of their source location. The Sq daily variation, the fields of the ring current, induced currents in the earth, and the conventional internal fields of the crustal anomalies and the main dipole, are represented above and below the orbit by the outer and inner functions, respectively. We effectively remove the contribution of the main dipole and the crustal anomalies to the long wavelength fields in these regions by subtracting the scalar potential of the main dipole and a reference field such as the MOST 6/80 (Langel et al.,

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1981). With this subtraction, and the substitution of mean orbital radius for the mean earth radius, equation 2 describes the residual scalar potential for the long wavelength external fields such as the ring current and the daily variation.

Since the model regression fit is to be applied to a single orbit of data, the spherical harmonic expansion of equation 2 may be replaced by a planar harmonic expansion of the scalar magnetic potential as:

$$V = \sum_{n=0}^N \left\{ \left(\frac{o}{r} \right)^{n+1} [A_n \cos n\theta + B_n \sin n\theta] + \left(\frac{r}{o} \right)^n [C_n \cos n\theta + D_n \sin n\theta] \right\} \quad (3)$$

where V is the scalar magnetic potential, A_n and B_n are coefficients of the outer potential, C_n and D_n are coefficients of the inner potential, o is the orbital radius, N is the maximum order of the model (usually 8), and θ is the true anomaly of the satellite orbit.

To simplify the model, we assume the reference surface to be circular, i.e. $o = \text{constant} = 6800 \text{ km}$. To obtain coefficients A through D , we perform the appropriate spatial derivatives of V for the magnetic field components, H and Z , and solve a least squares normal equation using the appropriate MAGSAT vector magnetometer observations. The matrix equation to be solved is:

$$Y = [M]X \quad (4)$$

where

$Y = [Z_1, H_1, Z_2, H_2, \dots, Z_m, H_m]^T$
are the measured data values of the horizontal and vertical fields H and Z , respectively, and

$X = [A_1, B_1, C_1, D_1, A_2, \dots, B_N, C_N, D_N]^T$
are the coefficients for the potential, and

$$[M] = \begin{pmatrix} \frac{1}{o} \end{pmatrix} \begin{bmatrix} -2\left(\frac{o}{r}\right)^3 \cos\theta_1 & -2\left(\frac{o}{r}\right)^3 \sin\theta_1 & \cos\theta_1 \sin\theta_1 & \dots & N\left(\frac{r}{o}\right)^{N-1} \sin N\theta_1 \\ -\left(\frac{o}{r}\right)^3 \sin\theta_1 & \left(\frac{o}{r}\right)^3 \cos\theta_1 & -\sin\theta_1 & \dots & \dots \\ -2\left(\frac{o}{r}\right)^3 \cos\theta_2 & -2\left(\frac{o}{r}\right)^3 \sin\theta_2 & \dots & \dots & \dots \\ -\left(\frac{o}{r}\right)^3 \sin\theta_2 & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ -\left(\frac{o}{r}\right)^3 \sin\theta_m & \dots & \dots & \dots & N\left(\frac{r}{o}\right)^{N-1} \cos N\theta_m \end{bmatrix}$$

Assuming $m \gg N$, this regression analysis can be completed by solving the least-squares normal equation:

$$\mathbf{X} = [\mathbf{M}^T \mathbf{M}]^{-1} [\mathbf{M}^T \mathbf{Y}] \quad (5)$$

The coefficients obtained by this regression are then substituted into equation 3 and the associated derivatives to calculate field components. A value is obtained for the scalar potential and the field components due to the ring current, Sq daily variation, and any other long wavelength field which may be present in the measurement residuals. This calculated field value is then subtracted from the observations to obtain a field value corrected for long wavelength fields from the ring current and the daily variation.

It should be noted that this procedure is similar to that used for adjustment of potential field data to a common altitude. By assuming a constant radius for ϕ , we are in effect adjusting the component data to that altitude.

While this regression approach is apparently well-suited to routine correction of satellite data, it is susceptible to aliasing errors due to the use of the same frequencies in the inner and outer functions. Indeed, an early formulation of this method for total field intensity failed for this reason. Simulation tests using calculated data showed that reformulation in terms of horizontal and vertical field components relieved this problem. These simulation tests involved assuming values for the coefficients to simulate field data along a hypothetical orbit. These data were subjected to the regression procedure described above, and the recovered coefficients compared with the coefficients used to simulate the data. The satellite orbit radius for these tests was assumed to be given by

$$R = 6800 + 100 \sin \theta, \quad (\text{km}).$$

To simulate the fields due to the ring current and Sq, twelve coefficients were specified for the outer functions and twelve for the inner functions ($N=3$). A total of 512 values around the orbit were calculated for the horizontal field component and the vertical component. The results of this simulation test and others, including tests using actual MAGSAT data are described in the next section.

RESULTS

This section presents results of simulation tests of the regression procedure, followed by a demonstration of the regression/harmonic filter on one orbit of actual MAGSAT data.

Simulations

For the test using simulated data, the recovered coefficient values are shown in Table 1 in comparison with those assumed values used in generating the simulated data.

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TABLE 1

Field Coefficients (nT*km)

order	<u>Assumed Values</u>				<u>Recovered Values</u>			
	A	B	C	D	A	B	C	D
1	-238600	149900	-19850	-3801	-238600	149900	-19850	-3801
2	151500	30210	12680	-37260	151500	30210	12680	-37260
3	-156000	182800	15570	75910	-156000	182800	15570	75910
4	128300	1336	-17770	-52680	128300	1336	-17770	-52680
5	53450	185900	11820	45430	53450	18590	11820	45430
6	-4718	122400	-10190	-4181	-4719	122400	-10190	-4181

The regression process was able to recover the assumed starting values of the coefficients quite well. In fact, the only error is one part in 4718 in the sixth harmonic.

To obtain an estimate of the degree of independence of inner and outer terms of the same order, this simulation test was repeated, using all twelve harmonics of the inner functions and the first harmonic of the outer functions to simulate the data. Values were recovered for all twelve outer coefficients. The results of this test are shown in Table 2.

TABLE 2

Field Coefficients (nT*km)

order	<u>Assumed Values</u>				<u>Recovered Values</u>			
	A	B	C	D	A	B	C	D
1	-238600	149900	-19850	-3801	-238600	149900	-19850	-3801
2	151500	30210	0	0	151500	30210	0.1430	-0.1904
3	-156000	182800	0	0	-156000	182800	0.0233	-0.1910
4	128300	1336	0	0	128300	1336	-0.0496	-0.0857
5	53450	185900	0	0	53450	18590	-0.0164	-0.0563
6	-4718	122400	0	0	-4719	122400	0.0470	-0.0374

The regression process was able to recover the assumed starting values of the inner functions without error, and the error of commission in the recovered values of the outer functions is less than 0.2 nT*km. For a geocentric radius of 7000 km (higher than the MAGSAT orbit), the field error corresponding to this value is minuscule. Thus we can conclude there is good orthogonality between inner and outer functions of the same order. This is probably due to the use of a complete orbit (and complete cycle of external field variation) of data in the regression filter, since these functions differ only by a factor (o/r) instead of (r/o). The eccentricity of the MAGSAT orbit provides about 200 km difference in radius between apogee and perigee, so similar separation of functions should obtain when processing actual MAGSAT data.

The sensitivity of the regression process to aliasing between the harmonics of different order is illustrated by a simulation in which data was simulated using outer and inner functions of orders 1 through 9, but coefficients were recovered only for orders 1 through 6. This simulation test is summarized in Table 3.

TABLE 3

Field Coefficients (nT*km)

order	Assumed Values				Recovered Values			
	A	B	C	D	A	B	C	D
1	-238600	147700	-19850	-3801	-244200	152700	-13300	954
2	151500	30210	12680	-37260	148300	31890	16830	-35220
3	-156000	182800	15570	75910	-158200	184100	18710	77100
4	128300	1336	-17770	-52680	126700	2374	-15170	-51900
5	53450	185900	11820	45430	51710	187100	14100	45960
6	-4718	122400	-10190	-4181	-10890	115200	-8519	-4135
7	-53550	34280	-3806	-772				
8	8016	1015	858	-2082				
9	-2178	2094	235	916				

As can be seen, aliasing due to truncation can create some significant errors in the recovered coefficients. Coefficients A6 and C1 seem to have the largest errors, equivalent to 0.9 and 0.6 nT respectively at a radius of 7000 km. Even though these errors are negligible, since they are much larger than the errors seen in previous simulations, they serve to raise a caution flag. In the regression of actual data, a similar situation will be presented, with higher order information being present in the field measurements in the form of the crustal magnetic anomalies. If this information aliases into recovered correction coefficients, then the correction will remove some of the crustal signal. This should be tested further in future studies.

MAQSAT Data

As a demonstration of the regression/harmonic filter method, a MAQSAT orbit from early in the mission was chosen at random. The orbit chosen was number 1176 on November 5, 1979. The subtrack of this orbit is shown in Figure 5, starting over the Siberian arctic, descending through the Indian ocean, and ascending over the eastern Pacific to end again in the Russian arctic over the Kara Sea. The distance between the end points is only about 400 km. The field residuals for the horizontal (X and Y) and the vertical (Z) components are plotted in Figure 6 with reference to a circular baseline. The field values are plotted at a scale of 50 nT per inch radially from the circle (positive outside) and one complete revolution of the circle corresponds to one orbit period of about 5597 seconds. Note the presence of a short data gap over the southeast Pacific. This gap is less than the shortest wavelength of the correction functions, however, so no untoward results are expected. This plot represents a slight decimation of the original MAQSAT data, as only every third point was selected for processing. Even at that, there are more than 2000 data points represented. Also shown in Figure 6 is the satellite altitude, plotted at 100 km per inch

relative to a circular baseline at 400 km. There is no obvious visual correlation between the magnitude of the field residuals and the altitude of the spacecraft.

As with the simulation tests, the reference radius was chosen as a constant at 6800 km. The data were first processed through the regression analysis to recover 4th order coefficients for both the inner and outer functions. An additional parameter, A_0 , was added to this regression analysis to remove constant biases in the residuals. The coefficient values are shown in Table 4.

TABLE 4
Field Coefficients (nT*km)

order	Assumed Values					Recovered Values			
	A	B	C	D		A	B	C	D
0	0	-	-	-	:	-10	-	-	-
1	0	0	0	0	:	21754	-44320	-44608	-31163
2	0	0	0	0	:	7454	-4276	-292	5643
3	0	0	0	0	:	-18949	2873	11331	-13931
4	0	0	0	0	:	10797	2428	9490	2392
5	0	0	0	0	:	-1432	305	-3175	7577
6	0	0	0	0	:	-996	-1733	-889	-2613
7	0	0	0	0	:	-677	2247	-376	1116
8	0	0	0	0	:	-1975	-1873	-252	-661

Based on these coefficient values, a correction field was calculated at each data point and subtracted from the observed data to give a corrected residual. Typical profiles of the correction fields for the horizontal and vertical fields are shown in Figure 7. Note that the inner and outer corrections have similar frequency content, as expected. The magnitude of the corrections is typical for undisturbed ring current and daily variation fields.

Figures 8 and 9 show the horizontal and vertical field residuals, respectively, before and after correction. Note the complete removal of long wavelength signals in the residuals. The corrected residuals are much reduced, but the short wavelength signals are preserved, including the obvious spikes in the polar regions caused by field aligned currents. For the horizontal component, the RMS of residuals is reduced from 28.31 nT to 14.47 nT, a reduction of 24.33 nT RMS, while the improvement in the vertical component is 10.95 nT RMS, from 16.29 to 12.06 nT RMS.

CONCLUSIONS

Because of a lack of timely data from magnetic observatories, the presently available method for modelling the daily variation fields is not practical for routine correction of MAGSAT vector data. Regression analysis of satellite data, using a long wavelength model for the ring current, was found to yield as good or better results as a more complicated model using spherical harmonic coefficients which were

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functions of magnetic indices DB and Dst . This regression approach is more amenable to routine corrections because of its independence of indices derived as global averages from terrestrial observatory magnetograms. Therefore, to meet the need for a more general correction algorithm, and one which could be employed on a routine basis to MAGSAT vector data by all investigators, a regression/harmonic filter procedure was developed which corrected for both the ring current and the daily variation as well as other long-wavelength external fields.

This procedure uses the known spectral content of the external field current distributions to define the order and form of the mathematical formulation, and uses the observed field component residuals to determine the optimum coefficients for correction of data in that particular MAGSAT orbit. In addition to correcting for long-wavelength external field variations, it also has the capability of reducing all observations to a common altitude on an orbit by orbit basis, without prior knowledge of conventional geomagnetic field indices.

Simulation tests of this procedure show good separation between inner and outer functions of the same frequency, and excellent recovery of simulated external field model coefficients. Aliasing due to truncation, which will certainly occur in operational use of the procedure, should cause correction errors of less than 1 nT. Although this is relatively small, it should be reevaluated in a more realistic test using actual data whose spectral characteristics are known.

Tests of this procedure on a MAGSAT orbit selected at random shows visible improvement in the field component residuals, and qualitatively good correction for the long wavelength external fields expected from the ring current and the daily variation. Horizontal component residuals are reduced by 24.33 nT RMS, while the vertical component residuals are reduced by 10.95 nT RMS. These corrections agree with the expected magnitude of the combined ring current and daily variation field. Further evaluation of this procedure should include intercomparisons between colinear orbits before and after correction, and evaluation of cross-track gradients between adjacent orbits.

Thus the objective of this investigation, development of a method for routine removal of the most persistent external effects from the MAGSAT data, has been satisfied; despite circumstances which forced a change from the proposed approach. Not only has such a method been developed, but it has been tested in simulations to examine its limitations and prove feasibility. Its practical applicability has also been demonstrated by tests with actual MAGSAT data. The harmonic regression method also has the potential for reduction of the satellite vector data to a common altitude automatically, in addition to correcting for long wavelength external fields.

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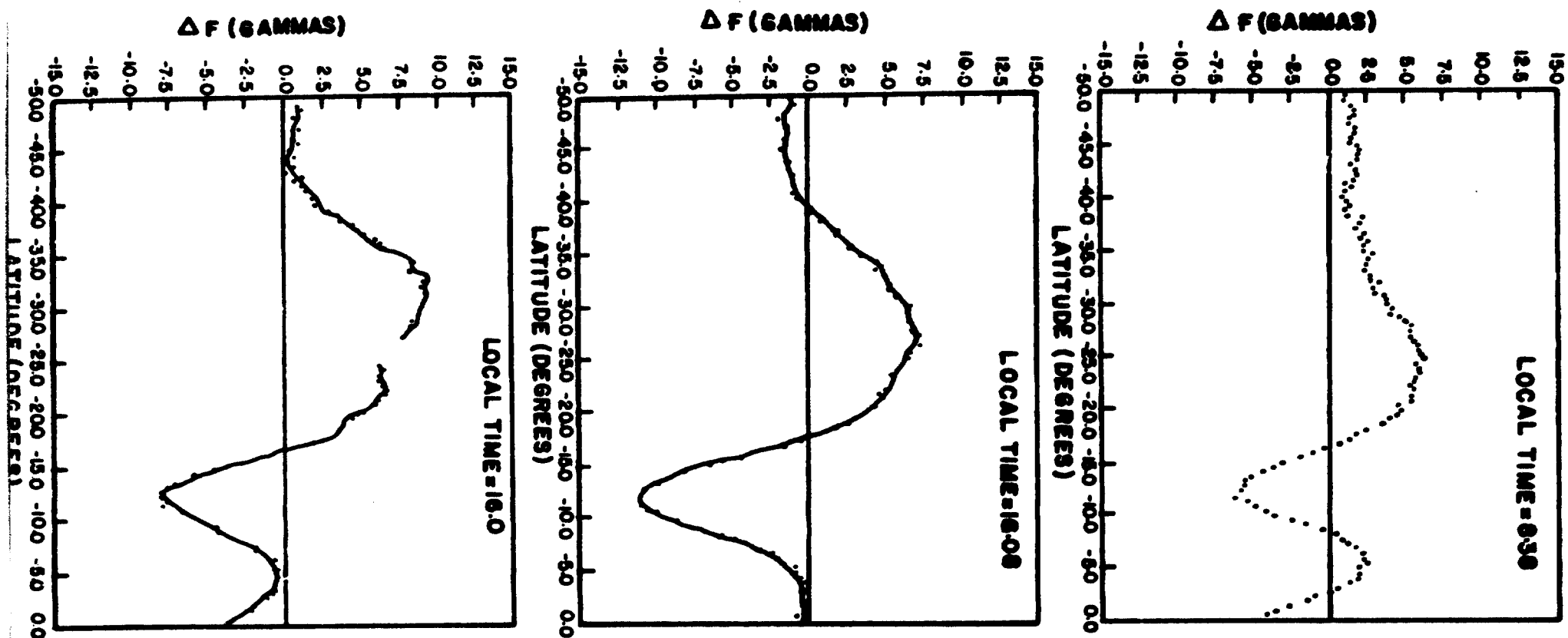


Figure 1. Scalar magnetic residual profiles from 3 colinear POGO passes, at about 80° W longitude, altitude 470 to 520 km. Note the presence of the equatorial electrojet of the daily variation at the magnetic equator, 10° S latitude (R. Lar-el, personal communication).

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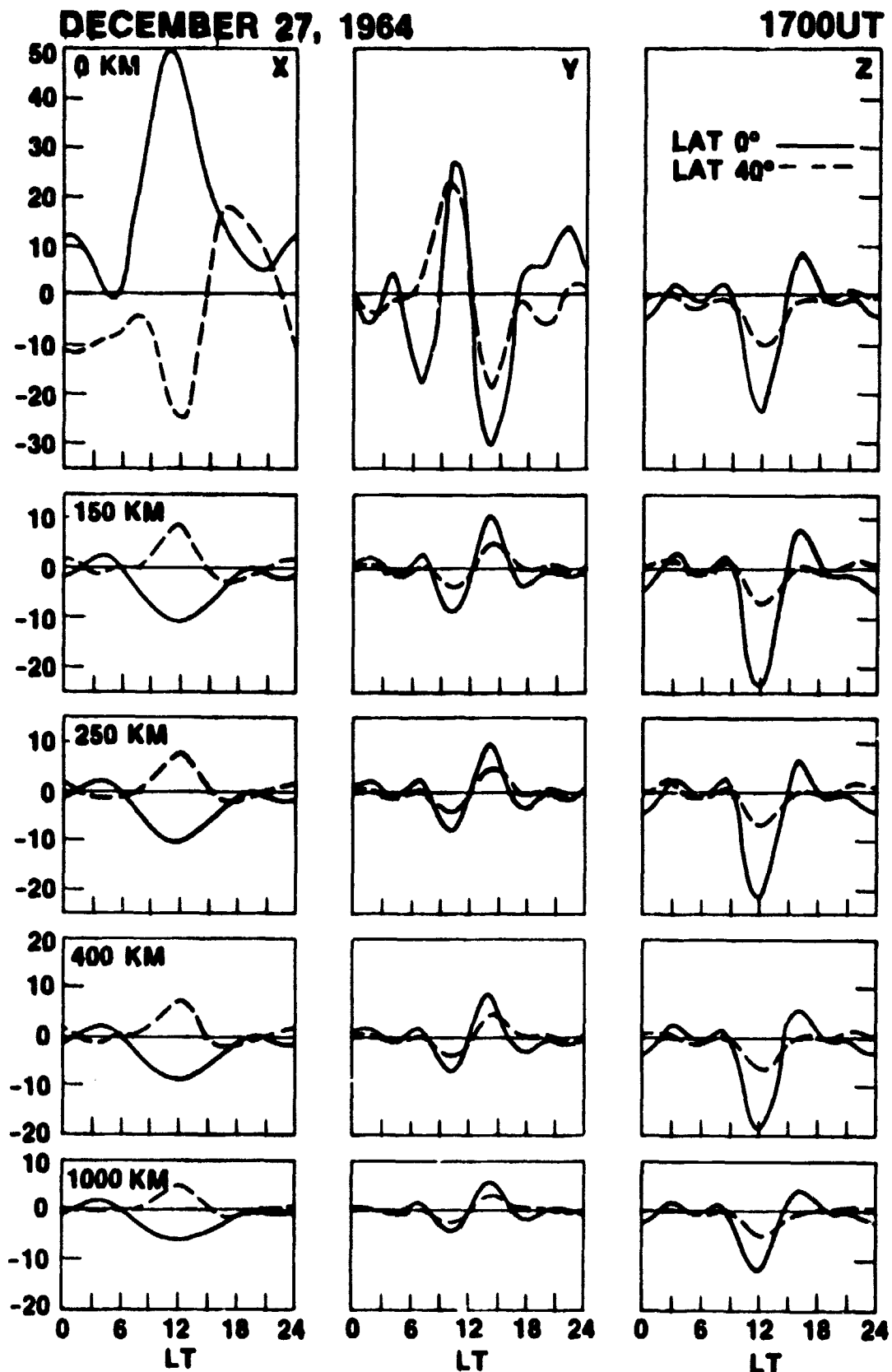


Figure 2. Component magnetic fields of the Sq current system, December 27, 1964. Note the variation with latitude, 0° to 40° North, and the constancy with altitude.

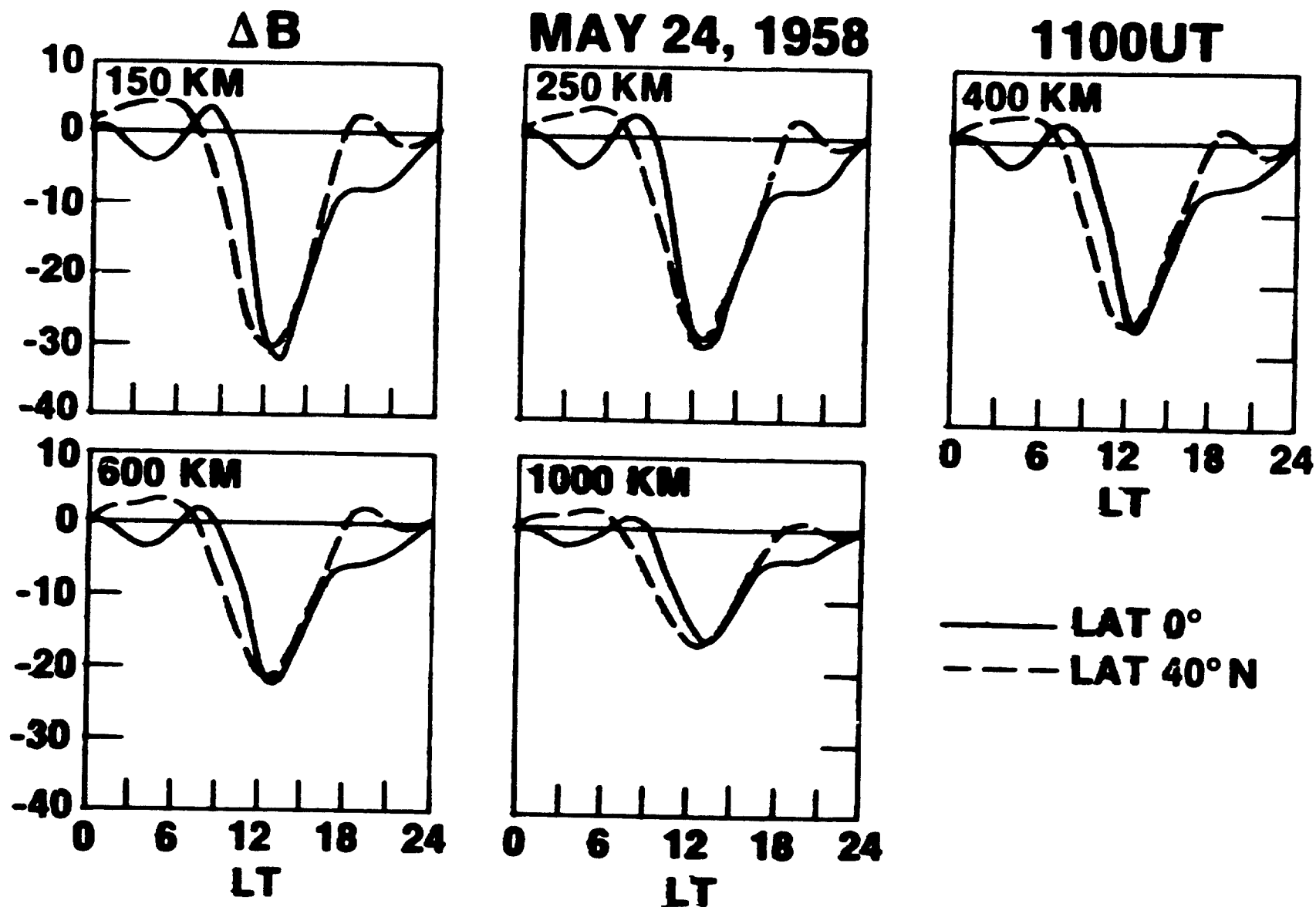


Figure 3. Scalar magnetic field of the Sq current system on May 24, 1958, a period of high solar activity.

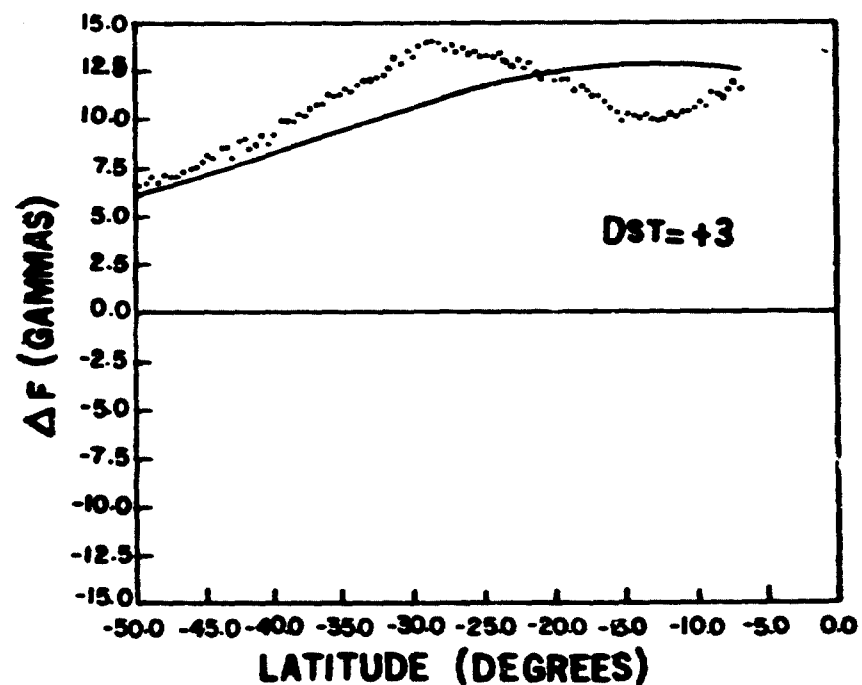
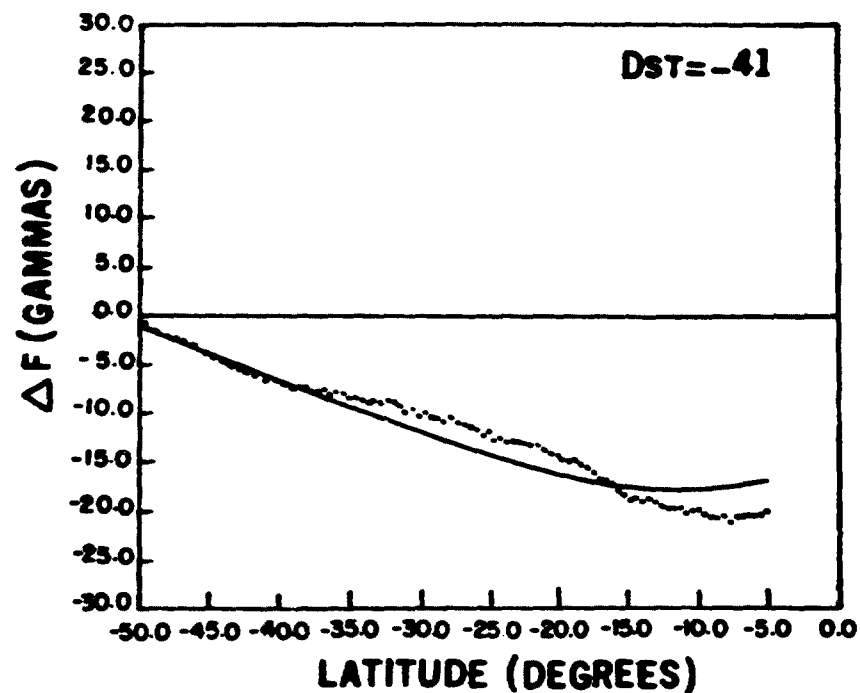
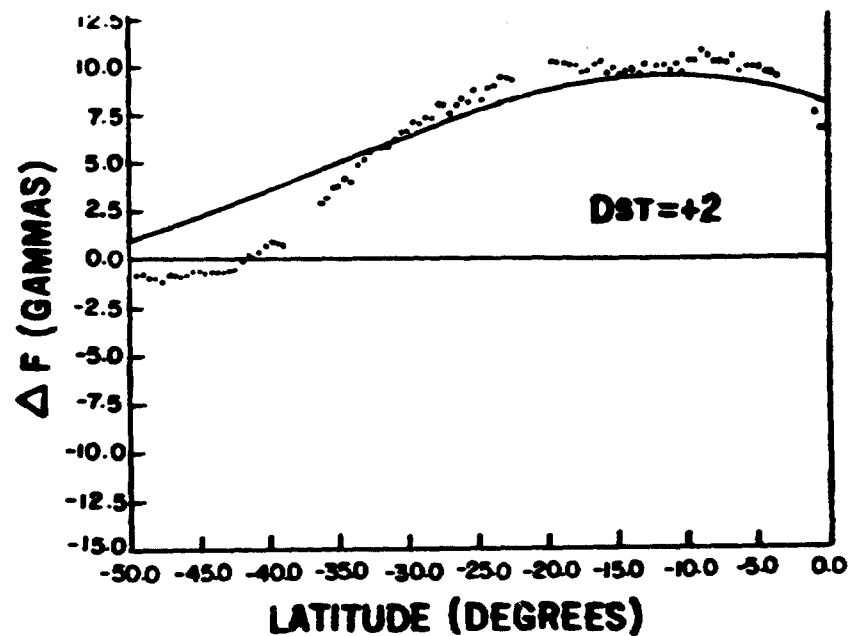
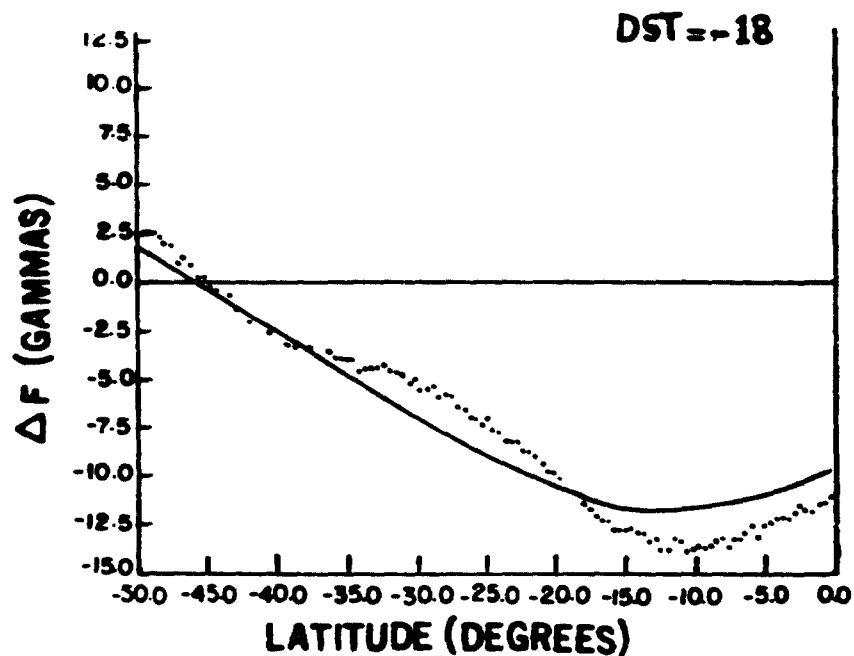


Figure 4. Scalar magnetic residual profiles from 4 colinear POGO passes, at about 82° W longitude, altitude 450 to 650 km (R. Langel, personal communication). The solid line shows the ring current correction calculated by Cain and Davis (1973). Dst indices are from Sugiura and Porom (1971).

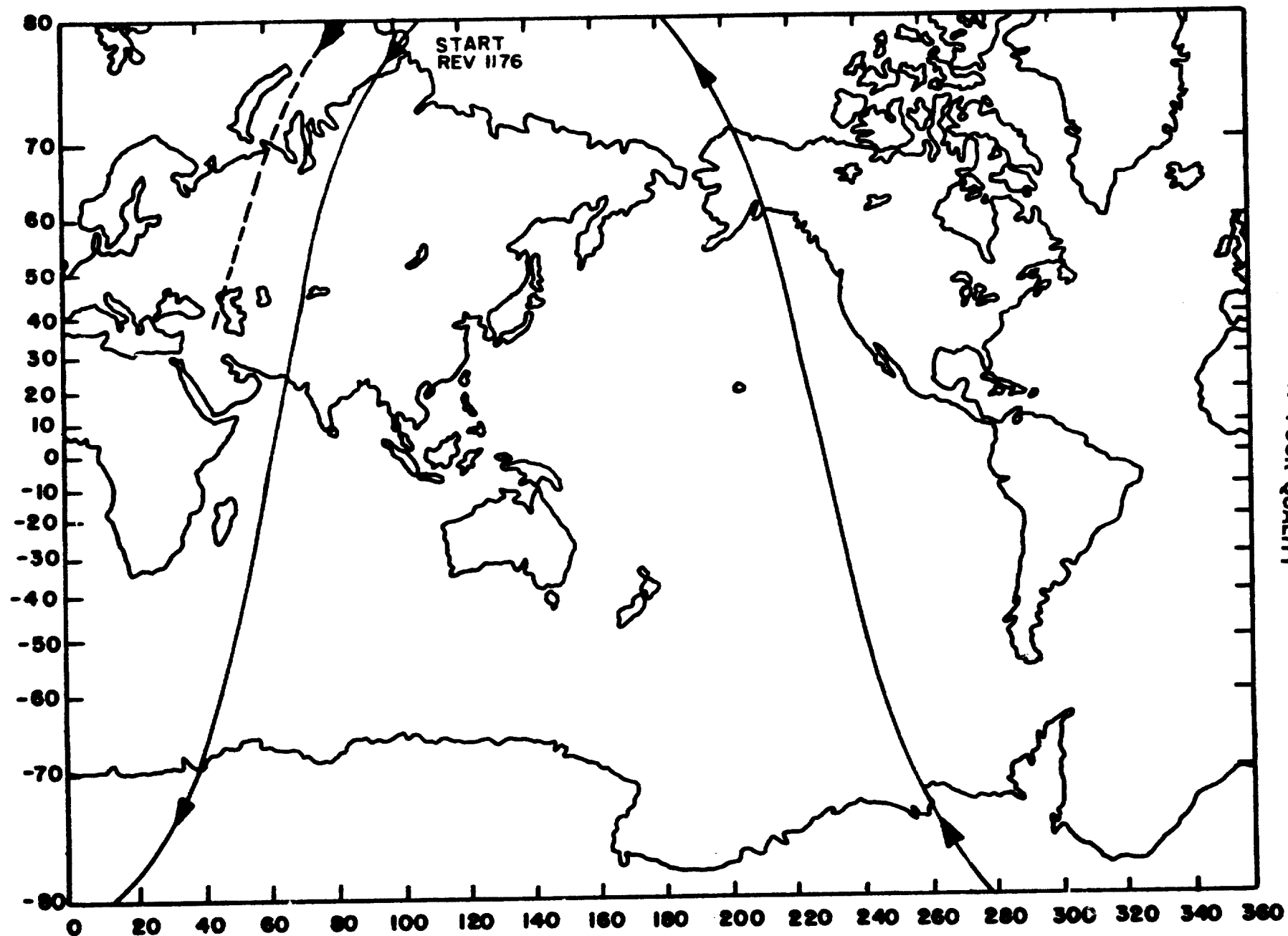


Figure 5. Subtrack of MAGSAT orbit 1176, November 5, 1979, for one orbit period.

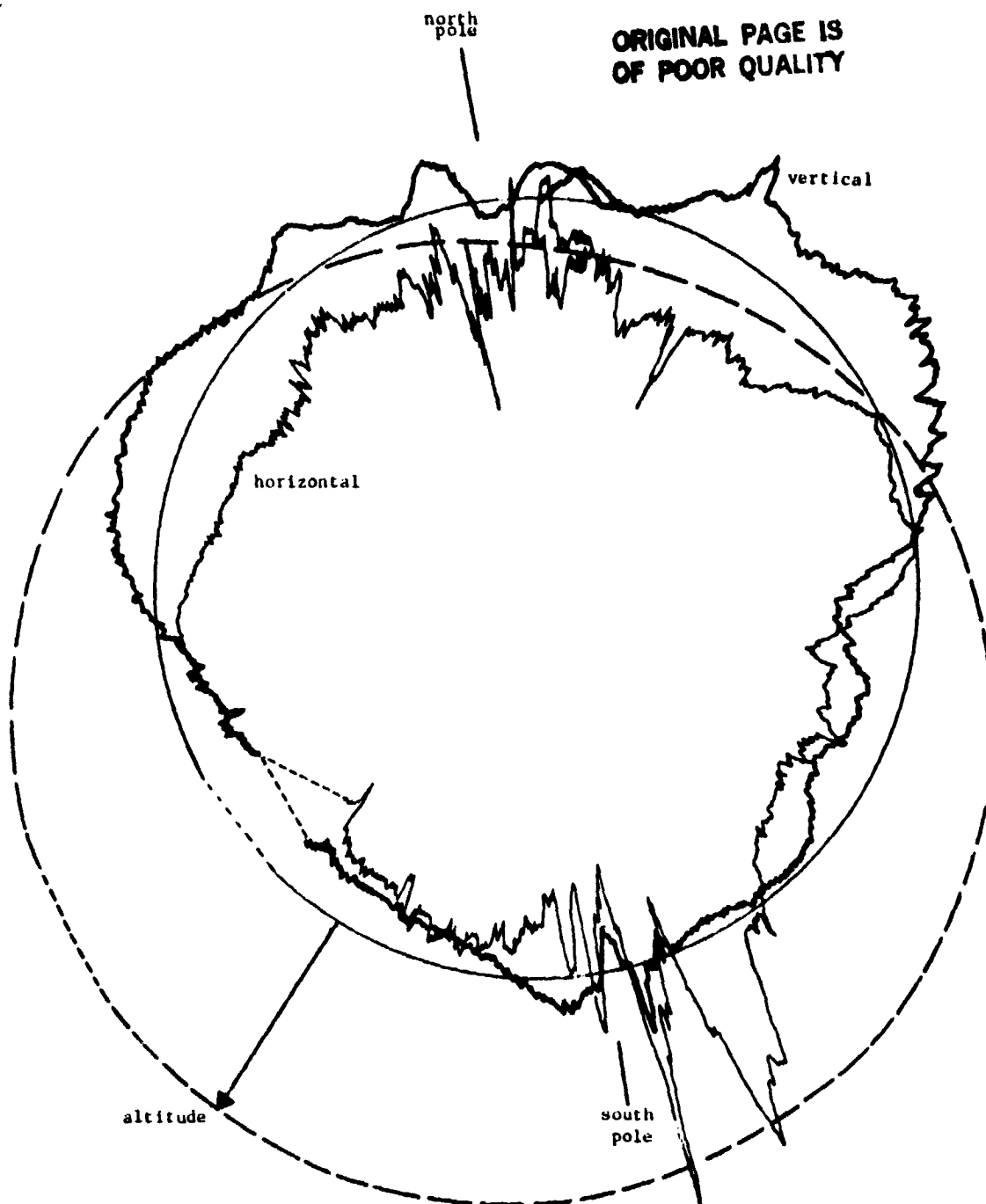


Figure 6. Horizontal and vertical component field residuals for MAGSAT orbit 1176, uncorrected for external fields. Field magnitude is plotted radially, (positive outward) at 50 nT per inch, relative to the circular baseline. The orbit starts at the top and proceeds clockwise. Note the evidence of large 3rd and 4th order harmonics in the residuals. Also shown is the satellite altitude relative to a baseline of 400 km, at 100 km per inch.

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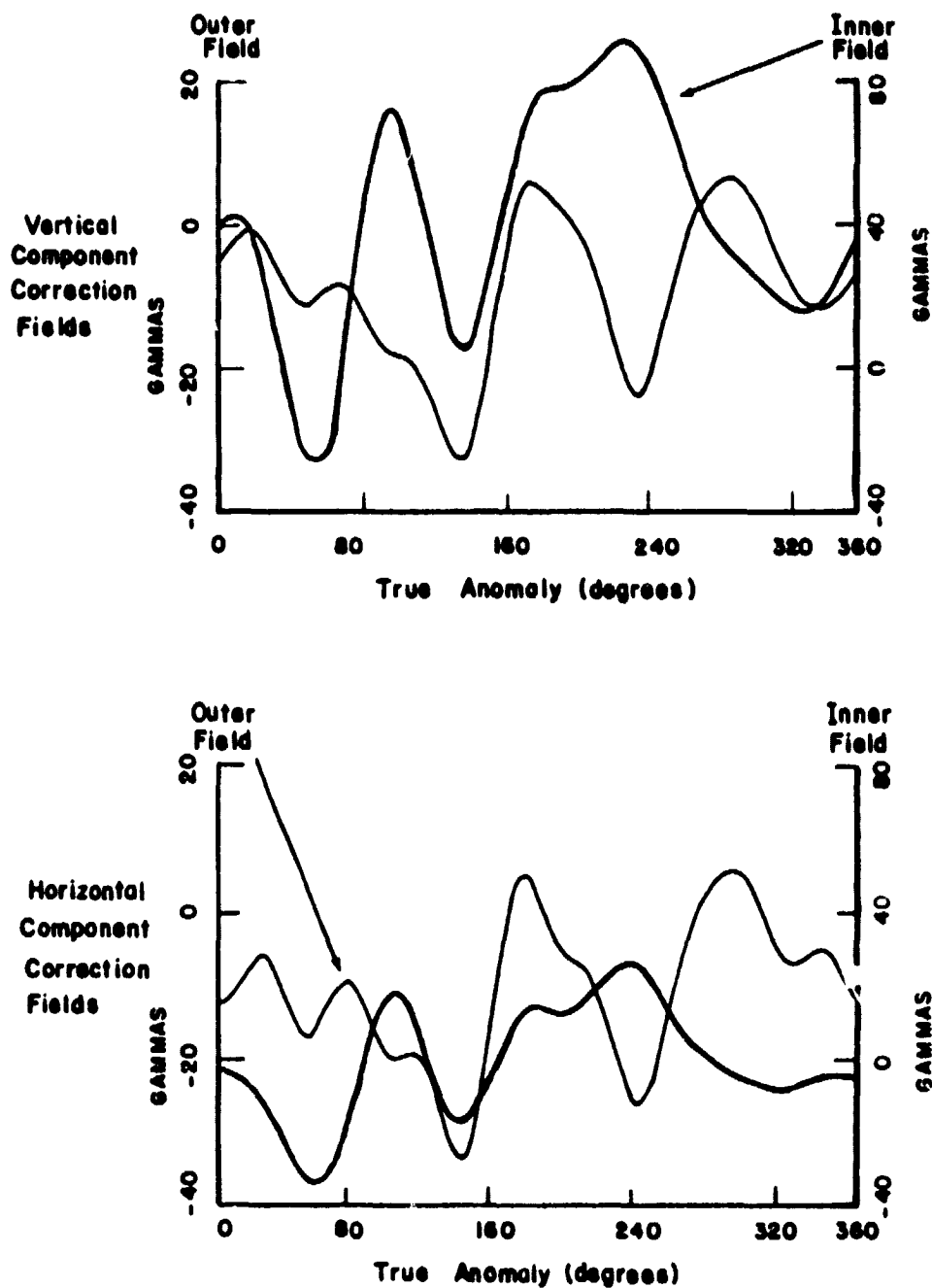


Figure 7. Typical correction profiles for the vertical and horizontal field components, outer and inner functions. Note the large 3rd and 4th order harmonics and the similarity in frequency content between the outer and inner functions. The peaks near the equator may correspond to the equatorial electrojet. The corrections magnitude is typical of the undisturbed ring current and the daily variation.

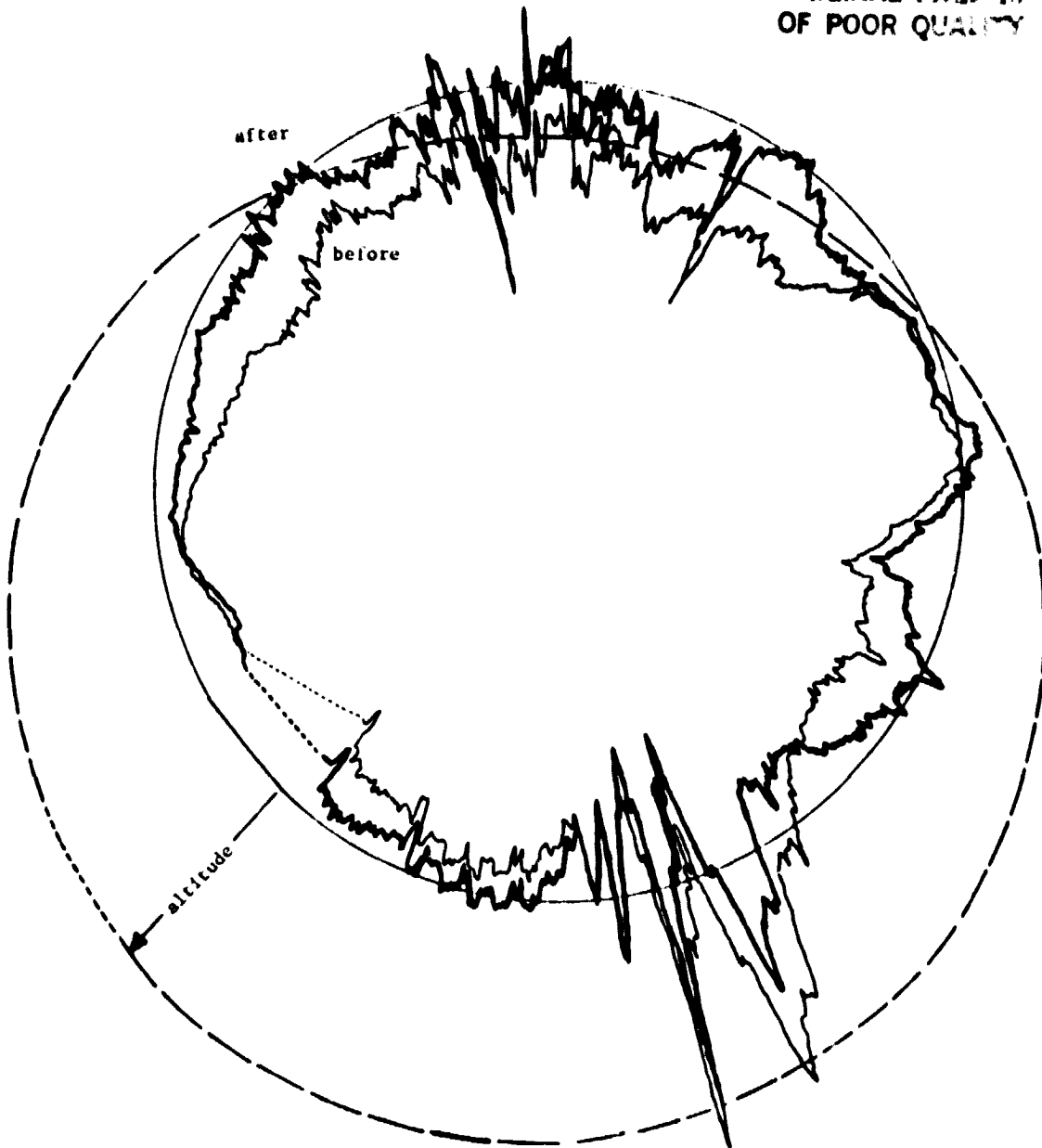


Figure 8. Horizontal component field residuals, orbit 1176, before and after correction. Note the dramatic reduction in negative bias in the residuals, and the diminution of the 4th order harmonic behavior. Large peaks near the poles are thought to be due to field-aligned currents. The RMS of residuals before and after is 28.31 and 14.47 nT respectively, for a reduction of 24.33 RMS.

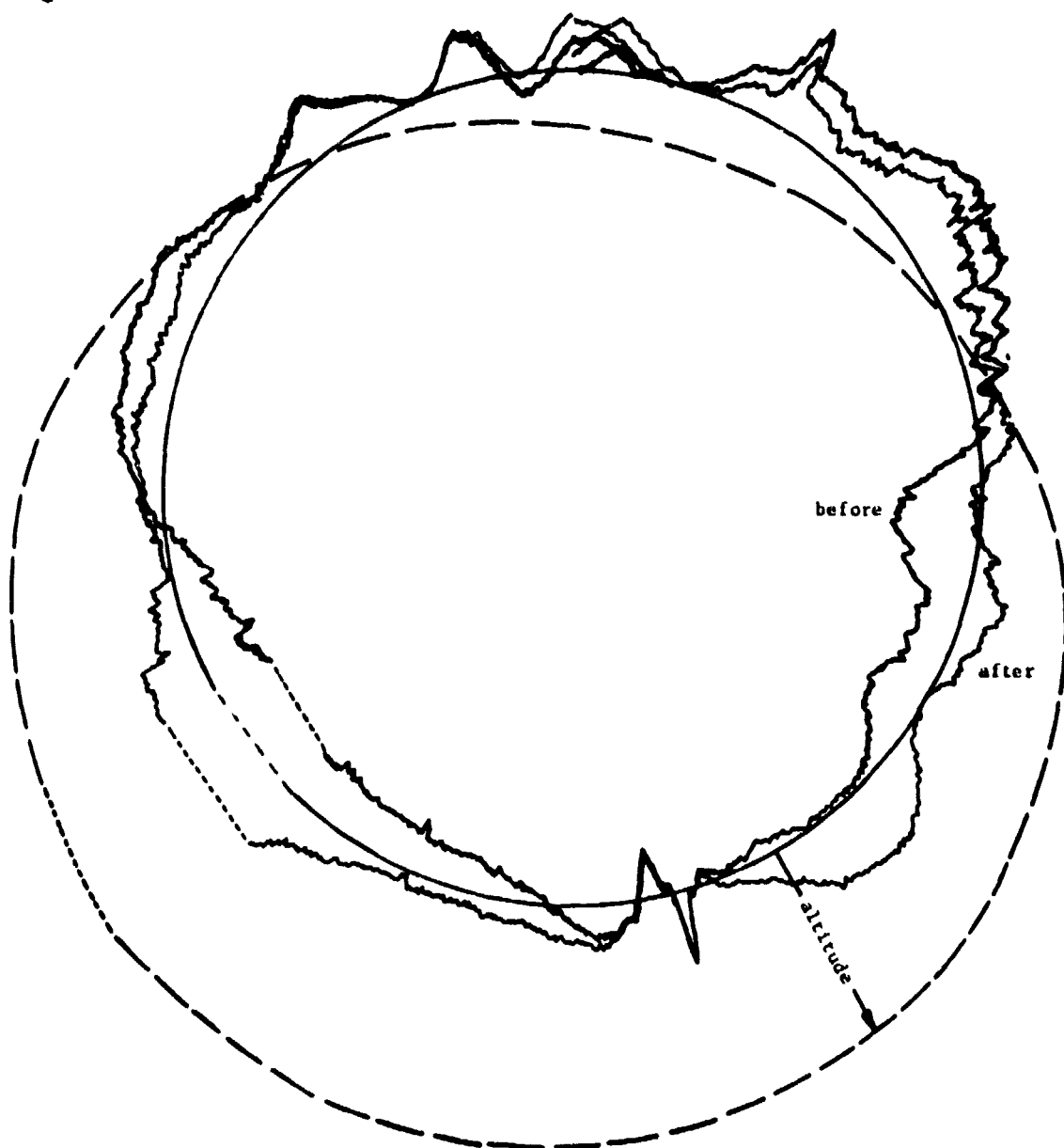


Figure 9. Vertical component field residuals, orbit 1176, before and after correction. Note the dramatic removal of 3rd order harmonic behavior, while preserving the shorter wavelength signals. The RMS of residuals before and after is 16.29 and 12.06 nT respectively, for an improvement of 10.95 nT RMS.